2006 Hydrogen Fuel Cells Technology Infrastructure Review Meeting

Low-Cost, High-Pressure Hydrogen Generator

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Project ID# PDP 2

Overview

Timeline

- Project Start: Jan 2003
- Project End: Dec 2007
- Percent Complete: 60

Budget

- Total Project Budget: $3.026M
  - DOE Share:$1.499M
  - Cost Share:$1.527M
- FY05 Funding
  - DOE: $400K
- FY06 Funding
  - DOE: $350K
- Cost Share Funding to Date: $1.08M

Barriers

DOE Technical Barriers for Hydrogen Generation by Water Electrolysis

- Q. Cost- capital cost, O&M
- R. System Efficiency

Technical Targets

- $600/kW for 10,000 scfd unit
- Stack efficiency = 76% (LHV)
- $2.85/gge H_2 in 2010

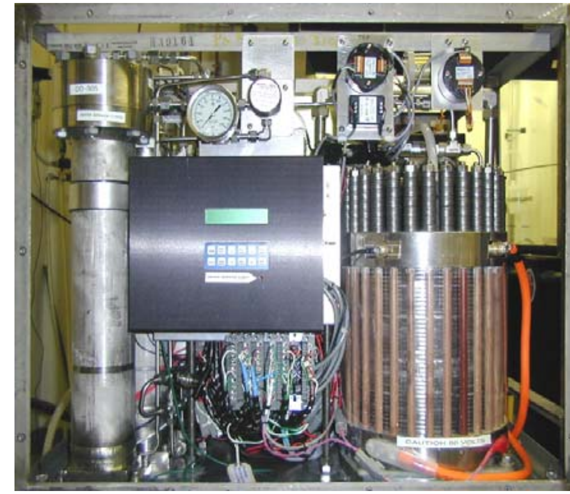
Partners

- General Motors
- Center for Technology Commercialization- Public Outreach and Education

Project Objectives

Overall Project

- Develop and demonstrate a low-cost, high-pressure PEM water electrolyzer system
  - Reduce capital costs to meet DOE targets
  - Increase electrolyzer stack efficiency
  - Increase electrolyzer hydrogen discharge pressure
    - reduce amount of mechanical compression required
  - Demonstrate a 3,300 scfd high-pressure electrolyzer operating on a renewable energy source



Advantages of GES PEM Electrolyzer

- PEM electrolyzers have higher efficiency than alkaline systems
  - Electricity is the key cost component in electrolyzer systems
  - Present GES performance is 1.75V at 1200 mA/cm^2
    - Stack efficiency = 71% based on LHV
  - With advanced membrane demonstrated 1.71V at 1200 mA/cm^2
  - Alkaline systems typically >1.85V at 300-400 mA/cm^2
- GES PEM differential pressure technology produces H_2 at high pressure (up to 3000 psig to date) with O_2 production at atmospheric pressure
  - Reduces system cost and complexity
  - Improves safety- eliminates handling of high-pressure O_2
- Cost is benefited by advances in PEM fuel cell technology

Approach

- Incrementally increase stack operating pressure through advanced seal and endplate design
  - 1000 psid in 2002; 2000 psid in 2004
  - Demonstrated sealing to 3000 psid in 2006
- Replace high-cost stack components with lower-cost materials and fabrication methods
- Increase operating current density to reduce cell active area (reduce stack cost) while retaining high efficiency
- Incrementally increase the system operating pressure
- System innovations to replace high-cost, high maintenance components
- Emphasize safety in design and operation

Objectives- Past Year

- Develop Lower-Cost Stack Components
- Decrease Parts Count/Cell
  - Applies to all operating pressures
  - Anode Side Membrane Support Structure (ASMSS)
  - Cell frames
  - Cathode Side Membrane Support Structure (CSMSS)
  - Cell Separator
- Increase Operating Current Density
  - Continued development of an advanced high-efficiency, high-strength membrane
    - Provides efficiency comparable to Nafion 112, but has 10x the strength
    - Operating at higher current density reduces number of cells, thereby decreasing stack cost

Stack Cost Reduction

- Initial stack cost reduction focused on the cathode side membrane support structure (CSMSS)
  - Previous Design was a hand-fabricated stack of expensive screens and shims- expensive raw material and assembly
  - Developed a low-cost single-piece CSMSS
  - Demonstrated in the EP-2 stack demonstrated in 2004
- Presently evaluating methods to further reduce cost of this part
  - Evaluating alternatives to current supplier
  - Developing methods to minimize post-fabrication processing

Stack Cost Reduction Since EP-2

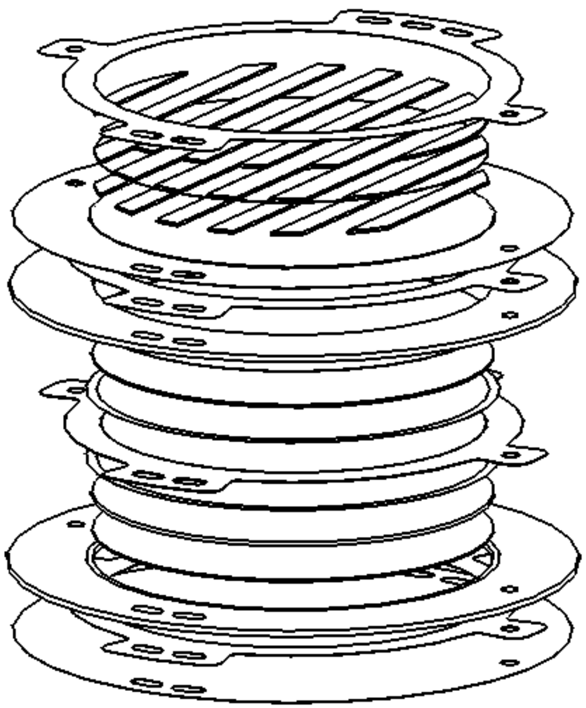
- *ASMSS*
  - Consists of 9 metal parts which are individually cut, plated, welded, cut again and assembled
  - Previously reported design of an alternate that consists of 4 parts
    - Could be supplied by a vendor as a single complete part
    - Expected to reduce ASMSS cost by 50%; an additional 25% reduction could be realized in high-quantity production
  - Evaluating feasibility of using a single-piece part
    - Working with vendors to develop cost-effective method for making part with acceptable tolerances
    - Currently evaluating properties of sample pieces

- *Thermoplastic Cell Frame*
  - Conduct fluids into/out of active area
  - Aids in pressure containment- highly stressed component
  - Presently these parts are molded and machined; machining accounts for 95% of part cost
  - GES worked with a Tier 1 automotive component supplier to design new frames and manufacturing methods
    - Evaluated several designs that eliminate machining
    - Test coupons successfully hydrostatically tested to 3000 psig
    - Analysis indicates leaching of contaminant from processing method
      - Continuing to pursue non-contaminating methods
- Successful development expected to reduce cell cost by 40%

- *Cell Separator*
  - Key component that must be compatible with high-pressure hydrogen on one side and oxygen at high potential on the other
  - Previous technology was a very expensive part consisting of two different valve metals
  - Evaluating several approaches
    - Treatments to reduce hydrogen embrittlement
    - Methods to bond low-cost materials

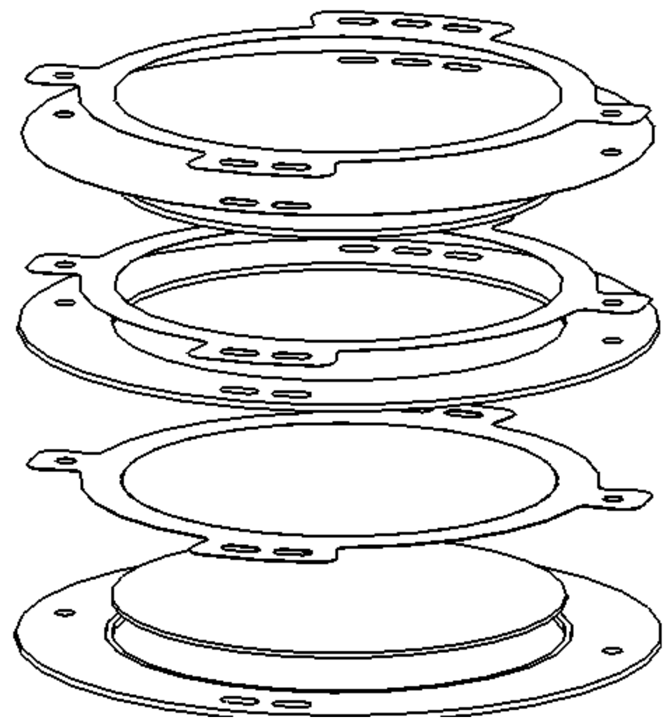
Progress in Part Count Reduction

2002



40 + Parts

Present Goal (2006)



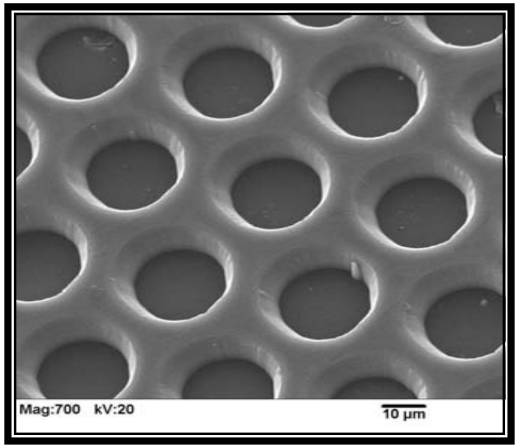
16 Parts

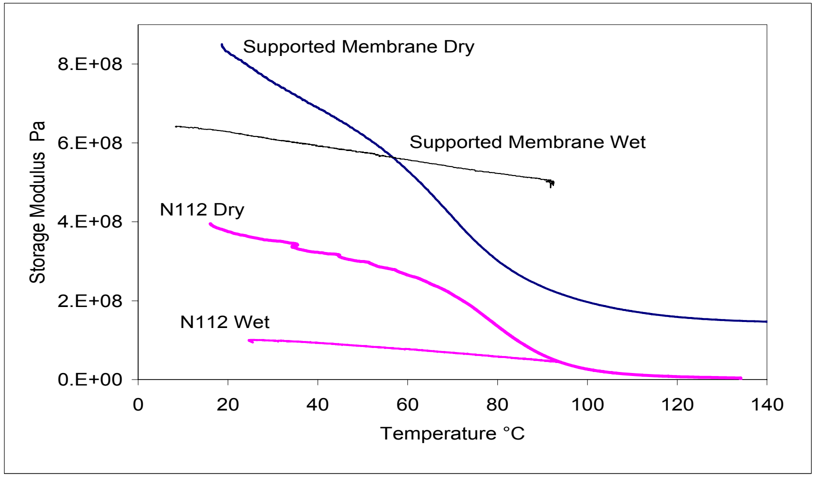
Increasing Operating Current Density

- High current density operation reduces stack active area, and therefore stack cost
  - Thin membranes have low resistance, allowing efficient operation at high current densities
  - Drawback is poor mechanical properties, limiting operation to moderate differential pressures
- GES has reduced the thickness of the Nafion membrane used from 10 mils to 7 mils, and has demonstrated performance and life of a 5 mil Nafion membrane in a short stack at 400 psid
  - However, thicker membranes are required at higher differential pressure
    - 5000 psid will require 10 mil standard membrane
- GES is developing an advanced supported membrane structure
  - Excellent mechanical properties- suitable for high differential pressure
  - High proton conductivity- equivalent to 2 mil Nafion membrane
  - Hydrogen and oxygen permeability equivalent to N112

Supported Membrane

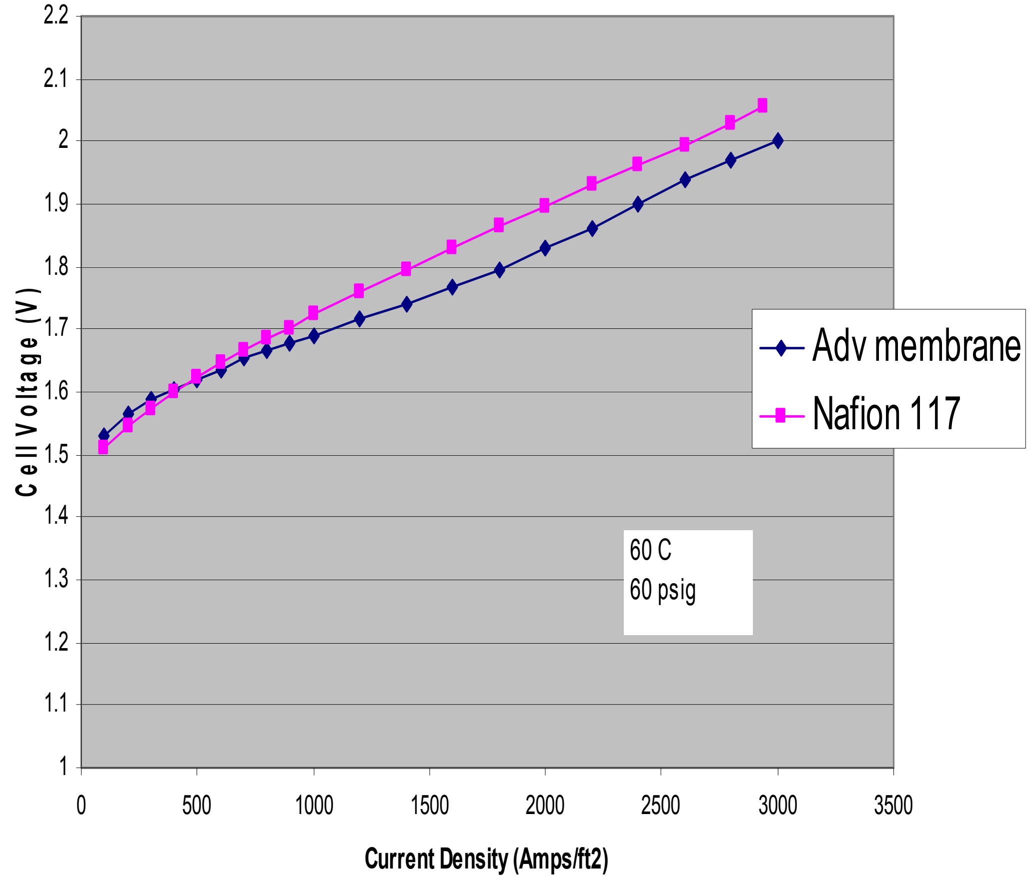
- Superior Mechanical Properties
  - No x-y dimensional changes upon wetting/drying or freeze-thaw cycling
  - Much Stronger Resistance to tear propagation
  - Superior to PTFE based supports
    10x stronger base properties
- Ease of MEA/Stack configurations
  - Direct catalyst inking onto membranes
  - Possible to bond support structures into bipolar frame to eliminate sealing issues
- Customization of MEA
  - Provide more support at edge regions and/or at ports



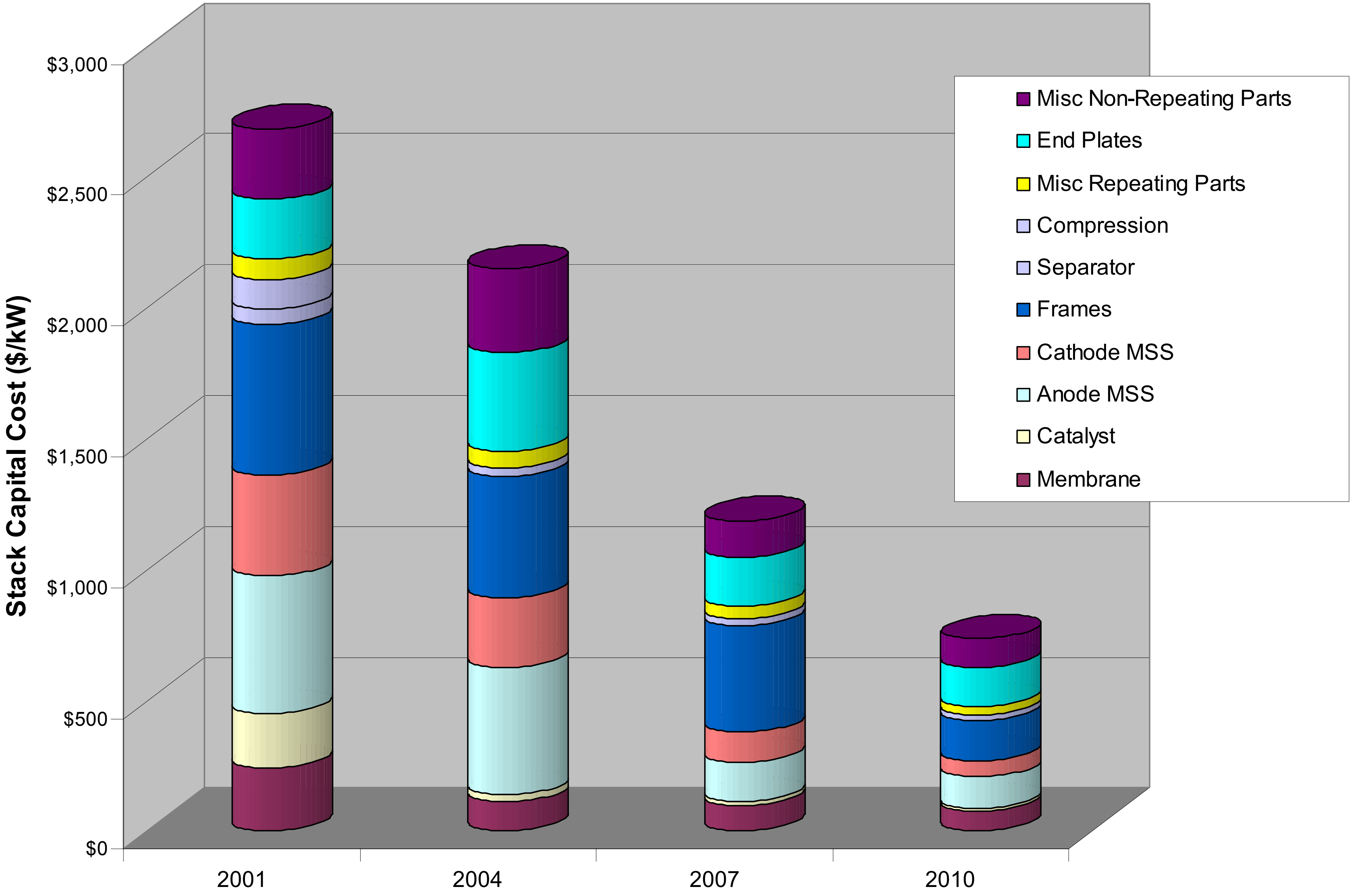


Demonstration of Advanced Membrane in 160-cm² cell

- Developed method for fabricating full-scale MEA
- Demonstrated sealing of membrane in cell
- Demonstrated efficient cell operation
  - Performance superior to Nafion 117 membrane



Progress in Stack Cost Reduction



EP-2 System

- System pressure (hydrogen production) was upgraded from 2000 psig to 3000 psig
- Design capacity
  - 140 scfd hydrogen
  - 25 kW system power

Future Plans

- Remainder of FY 2006
  - Continue focus on stack cost reduction
    - Develop single-piece ASMSS
    - Reduce fabrication cost of CSMSS
    - Evaluate low-cost cell frame fabrication methods
    - Develop lower-cost, long-life cell separator
    - Demonstrate advanced membrane
  - Demonstrate low-cost materials and fabrication methods in a 10-cell stack

Future Plans

- FY 2007
  - Fabricate 3300 scfd stack and system
  - Conduct field-test of system, possibly at NREL

Summary

- GES PEM Electrolyzer has potential to meet DOE cost and performance targets
- GES has made significant progress in stack cost reduction
- Further development of a high-strength, high efficiency membrane is recommended
  - Demonstrate reproducibility and durability
  - Decrease fabrication cost

Response to Reviewers' Comments

- Relying too much on low-cost electricity to achieve the cost targets
  - Cost of electricity is the major cost component
    - Even at very high efficiency, low-cost electricity is required to achieve the target \$2.85/gge H_2
    - DOE target is based on \$0.04/kWh
  - Advanced membrane will significantly improve electrolyzer efficiency
- Little collaboration
  - Program is primarily an engineering program
    - GES is collaborating with a number of component vendors and materials suppliers to develop advanced materials and manufacturing methods

Publications and Patents

- “Electrolyzer System Including Combination Gas Storage Vessel and Gas/Water Separator" (T. Norman and E. Schmitt); Patent Application Filed November 2005.

Critical Assumptions and Issues

- Hydrogen storage pressure for refueling
  - Present program is aimed at H_2 production at 5000 psig
  - DOE target has been increased to 6700 psig
  - Auto manufacturers are evaluating storage at >10,000 psig
  - GES economic studies indicate lowest cost for PEM electrolyzer operating at 1200-1500 psig, with single-stage compressor to reach storage pressure
- Cost of electricity is key variable in electrolyzer economic analysis
  - GES uses $0.035/kWh in our model